# Optical snake-based segmentation processor using a shadow casting incoherent correlator.

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What is believed to be the first incoherent snake-based optoelectronic processor that is able to segment an object in a real image is described. The process, based on active contours (snakes), consists of correlating adaptive binary references with the scene image. The proposed optical implementation of algorithms that are already operational numerically opens attractive possibilities for faster processing. Furthermore, this experiment has yielded a new, versatile application for optical processors. 

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Since the first optical correlator was designed by VanderLugt,[1] such optical processors have been widely studied for use in optical pattern recognition applications. In the case of nonoverlapping noise, introduced in Ref. 2 in the context of correlation filters, statistical algorithms have been used with success for localization of targets of known shape.[3] However, only a small number of optical processors operate with segmentation.[4–6] Such operation can be achieved with active contours, also called snakes,[7] obtained by deformation of a polygonal curve to match the contour of the object that is to be segmented. Recently, new approaches to snake-based segmentation of objects, in particular the statistically independent region snake, were proposed.[8] This approach takes into account the statistical signatures of regions to extract the object from the background. These new segmentation algorithms can be expressed by use of correlation operations. The implementation proposed in this Letter uses an optoelectronic architecture to show that an optoelectronic processor can also allow one to determine the shape of the target. The choice and the design of the optical processor are presented. Simulations and experimental results from the optical processor are illustrated with real and noisy images.

Several criteria that are adapted to different noise models and that one must minimize to adapt the snake to the target's shape were proposed in Ref. 9. The corresponding statistical laws allow the snake to differentiate the regions according to their surfaces and the variance and mean of their histograms, and the snake is able to move and progressively match the contour of the object to be segmented. These new algorithms are aimed at segmenting real scenes, even if they are blurred or corrupted by noise. In this Letter the Gamma law[10] layout for gamma density probabilities is considered. The corresponding criterion, $J$, operates on the mean and the surface of both the target and the background regions. The criterion contains only one correlation that can therefore be computed optically. The criterion to minimize is then

$$J(w,s) = N(w)\log(m) + [N - N(w)]\log(\overline{m}), \qquad (1)$$

with

$$m = \frac{1}{N(w)}(s \otimes w)_0, \qquad (2)$$

$$\overline{m} = \frac{1}{N - N(w)}\left[\sum_{i=1}^{N} s_i - (s \otimes w)_0\right], \qquad (3)$$

where $s$ is the scene containing $N$ pixels; $w$ stands for a binary window function that defines the shape of the target, so $w$ is equal to 1 within this shape and to 0 elsewhere. The purpose of the criterion minimization is to estimate the most likely shape $w$ of the target in the scene. $N(w)$ denotes the number of pixels in the window that are equal to 1. The snake delimits the inner (target) and outer (background) regions. The 0 index associated with the correlation means that it stands for the central value of correlation.

The Gamma law criterion, $J(w, s)$ [Eqs. (1)–(3)], contains one correlation. Such an operation may require significant time and depends on the scene size. An optical processor is therefore proposed for computation of this algorithm part to benefit from the advantages of optics. More precisely, the field of application of optical correlators that are able to track

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a target of known shape is thus enlarged to include the new capability of segmenting a target of unknown shape but approximately known localization. These two aspects, localization of a target of known shape and segmentation of an approximately localized target, are the two basic operations needed for a robust tracking system.

The optical operation is computed by an incoherent correlator based on the shadow-casting principle.[11] The major drawback of this architecture is the slight diffraction of the first plane, which is largely compensated for by three fundamental advantages. First, this architecture is not corrupted by coherent noises such as speckle. Second, in a coherent light processor, twisted nematic liquid-crystal spatial light modulators (SLMs), such as the ones used for this study, couple amplitude with phase. A shadow-casting incoherent correlator operates with intensity values and therefore is not perturbed by phase–amplitude coupling. Third, a processor with an incoherent light source is hardly sensitive to optical surface irregularities, whereas the performance of traditional optical correlators degrades drastically in the presence of such irregularities. Moreover, the processor benefits from a weak sensitivity to misalignment. In Fig. 1 the chosen processor configuration is presented.

The detection plane, $P_{\otimes}$, is located in front of planes $P_s$ and $P_w$. Therefore, a lens is necessary to image the correlation, $P_{\otimes}$, in the camera plane. The optical processor that performs the correlation between scene $s$ and window $w$ is shown schematically in Fig. 2.

The light path is the following: First, a collimated beam of coherent light goes through a rotating diffuser. The resulting beam is Gaussian and incoherent. The beam illuminates an SVGA SLM upon which scene $s$ is displayed. Then, the scene's shadow is cast on an SVGA SLM upon which window $w$ is displayed. Eventually, a lens images $P_{\otimes}$ (see Fig. 1) on the CCD camera. As the measurements in incoherent light are proportional to amplitude, the camera directly acquires the correlation product of $s$ and $w$ ($P_{\otimes}$). The criterion computation needs only the correlation center. Consequently, acquisition is averaged over a few CCD cells.

The Gamma law segmentation is applied to $249 \times 249$ pixel images. Figure 3(a) shows a car in a field. The photograph is slightly defocused and the contrast is bad, demonstrating that the processor is efficient for real images. The final segmentation results are shown in Figs. 3(c) and 3(d), superimposed on the original images. The number of nodes is 8 and is kept constant.

Nodes are moved stochastically, so the results may occasionally be slightly different. Indeed, the active contour, which works in a noisy environment, might converge toward several different local minima. Thus, the segmentation solution may not be unique, especially when the number of nodes is limited. This assumption is valid for both experimental and simulation results. Therefore, the experimental results shown in Fig. 3(c) can be regarded as satisfactory and quite close to the simulation results [Fig. 3(d)]. The experimental results shown in Fig. 3(c) were obtained after 192 iterations, and the simulation results [Fig. 3(d)] needed 208 iterations.

The proposed implementation is also effective with further overlapping white Gaussian noise, as shown in Fig. 4. One can optimize the algorithm to process high-quality segmentation with more nodes and more

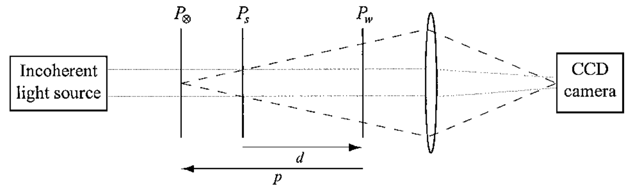


Fig. 1. Configuration of the optical processor. Plane $P_{\otimes}$ contains the correlation of the amplitude distributions located in planes $P_s$ and $P_w$.

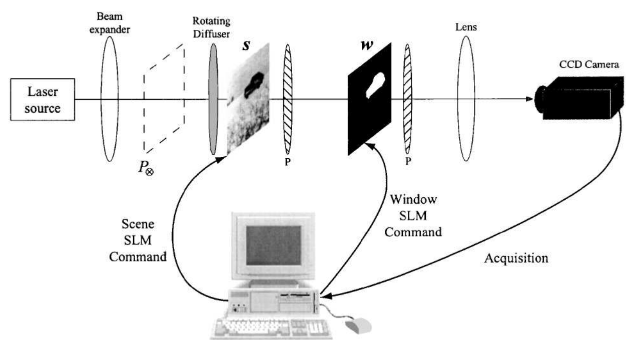


Fig. 2. Shadow-casting incoherent correlator.

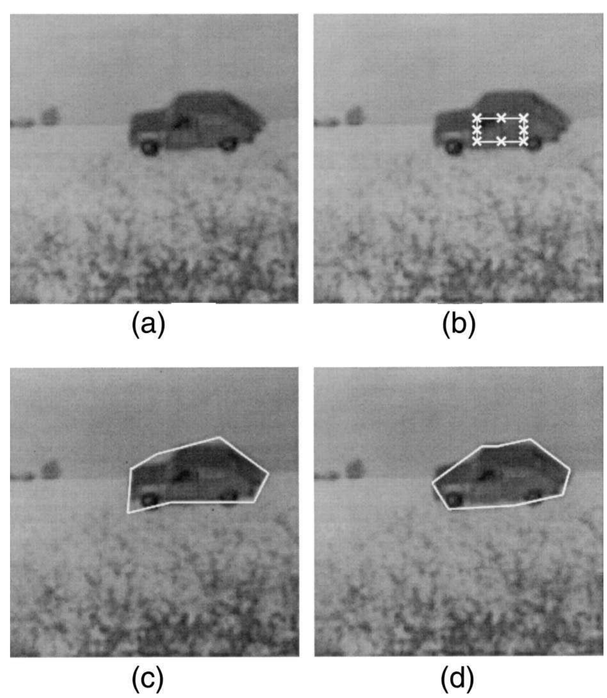


Fig. 3. (a) Input scene $s$. (b) Initialization of the snake, with its nodes marked by crosses. (c) Final state of the snake after the optimization of $J(s, w)$ obtained with the optical processor. (d) Simulation results.

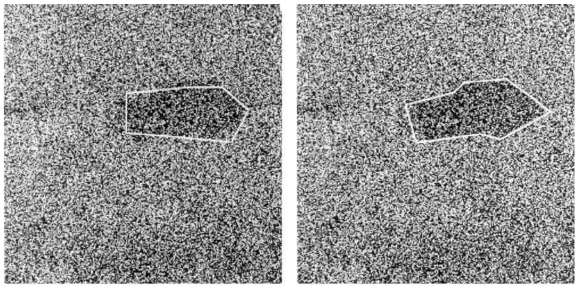


Fig. 4. (a) Experimental results of the optical snake implementation. (b) Simulation results.

iterations. From an experimental point of view, a progressive increase in the number of nodes does not really improve segmentation accuracy. Indeed, the more nodes the active contour contains, the more sensitive it is to noise, especially the noise resulting from the quantized gray levels.

The optical segmentation speed is limited (at present, with a twisted nematic liquid crystal SLM, it is 46 s with the optical processor) first, by the refresh time of the SLM and, second, by the camera's acquisition time. Recently, new ferroelectric SLMs with gray-level capabilities were built.[12] Their refresh rate is $\sim 1$ kHz and may provide much faster segmentations. Besides, the camera, which acts as one of the speed reducers, can be replaced with a linear fast photodetector, since only the correlation center is acquired. All these improvements are meant to reduce the segmentation time, which will tend toward 0.1 s.

In this Letter, what is believed to be the first implementation of a snake-based segmentation with a shadow-casting incoherent correlator has been described. This implementation is a novel approach to region-based segmentation that proves the feasibility of an optoelectronic approach. The main interest in developing this approach is to enlarge the field of applications of optoelectronic correlators. Of course, this is only a first step in the study of the optical processor described above. Preliminary experiments with other probability laws have also proved promising. Further improvements are needed for more-accurate, faster segmentation. Moreover, these promising results may lead to real-time optoelectronic segmentation. Also, scene preprocessing, which is required in many cases, will benefit from the optical design presented above. An optoelectronic architecture that can perform detection, tracking, estimation, and segmentation, and thus allow efficient target tracking or recognition in real time (i.e., at video frame rate), is now conceivable.

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